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June 5, 2017

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

Re: *Ex parte* presentation in IB Docket No. 11-109; RM-11681; IBFS File Nos. SES-MOD-20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091

Dear Ms. Dortch:

On June 1, 2017, Ivan Seidenberg, Chairman of the Board of Ligado Networks LLC ("Ligado"); Doug Smith, Ligado's Chief Executive Officer; Angela E. Giancarlo, of Mayer Brown LLP; and the undersigned (collectively, the "Ligado Representatives") met with Chairman Pai and Rachael Bender, Legal Advisor to Chairman Pai; and separately met with Commissioner O'Rielly and Erin McGrath, Legal Advisor to Commissioner O'Rielly. On June 5, 2017 the Ligado Representatives met with Commissioner Clyburn and Daudeline Meme, Legal Advisor to Commissioner Clyburn.

During these meetings, the Ligado Representatives discussed how Commission action could unlock 40 megahertz of mid-band spectrum, drive forward the transition to 5G, and hasten development of the Internet of Things ("IoT"). We asked the Commission to: (1) approve the spectrum plan and license modification applications submitted by Ligado in December 2015, and (2) issue a Notice of Proposed Rulemaking outlining the terrestrial use of adjacent spectrum currently allocated for only government use. The Ligado representatives stressed that making 40 megahertz of spectrum available on a nationwide basis is a big deal, and the Commission should act promptly to trigger these benefits. If the Commission acts expeditiously, Ligado expects to raise money in capital markets and invest those funds (which could total up to $800 million dollars) in our Nation's infrastructure, and thereby enable the creation of at least 8,000 new U.S. jobs.

As reflected in the record, the major GPS firms have indicated that they do not object to grant of the applications and Ligado's deployment of a terrestrial network with the power limits stated in the pending applications. The United States government should recognize the consensus of industry and scientific opinion expressed in this proceeding and put this vital mid-

band spectrum to work in building our 5G and IoT future. The issue raised late in the proceeding by Iridium relates to only 10 megahertz of the 40 megahertz in the plan. Ligado's current proposal is consistent with the Commission's *2003 ATC Order*, and the company is also willing to have additional discussions to resolve this issue as well. The Ligado representatives added that issuing a Notice of Proposed Rulemaking on the shared commercial use of the 1675-1680 MHz band continues the effort by the Commission, the Administration, and Congress to ensure that the Nation's vital spectrum resources are used efficiently and for the benefit of all Americans. That band is another important component of the pending plan to bring 40 megahertz of spectrum to facilitate the 5G transition and promote American leadership in the IoT.

The attached document expands upon these points and summarizes the several filings in this proceeding. Please contact the undersigned with any questions.

Sincerely,

/s/
Gerard J. Waldron
Counsel to Ligado Networks LLC

Attachment

cc: Chairman Pai
Commissioner Clyburn
Commissioner O'Rielly
Nicholas Degani
Rachael Bender
Erin McGrath
Daudeline Meme
Ron Repasi
Charles Mathias
Bob Nelson
Paul Murray
Paul Powell
Jennifer Tatel

Commission Action Can Unlock 40 Megahertz of Mid-Band Spectrum

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June 5, 2017

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I. Introduction and Summary

The Commission can unlock 40 megahertz of mid-band spectrum, drive forward the transition to 5G, and hasten development of the Internet of Things ("IoT") by taking two closely related actions: (1) approving the spectrum plan and license modification applications submitted by Ligado Networks (Ligado) in December 2015, and (2) issuing a Notice of Proposed Rulemaking outlining the terrestrial use of adjacent spectrum currently allocated only for government use. These companion decisions will enable the use of 40 megahertz of greenfield spectrum. Once this spectrum is available, Ligado plans to build a unique network that will maximize the capabilities of both the satellite and terrestrial spectrum by integrating them to achieve new levels of reliability, security, and pervasiveness that can be achieved only by using both capabilities.

If the Commission takes these actions promptly, Ligado expects to raise money in capital markets and invest those funds in our Nation's infrastructure. Ligado will invest up to $800 million dollars to begin to deploy a network uniquely suited to bringing 5G and IoT to railroads, trucking, autonomous vehicles, drones, and other critical infrastructure industries. These investments can create at least 8,000 new jobs.

As reflected in the record, the major GPS firms have indicated that they do not object to grant of the applications and Ligado's deployment of a terrestrial network with the power limits stated in the pending applications.[1] Three extensive engineering tests have been conducted in search of possible impact on the installed base of GPS devices, involving over 5,000 hours of lab tests: one by an expert firm retained by Ligado, one by a facility sponsored jointly by the Department of Commerce and Department of Defense, and one by the Department of Transportation (DOT). All three tests have vindicated the judgment of the GPS firms: devices in every category of the GPS ecosystem would not experience actual harm if Ligado were permitted to deploy a terrestrial network in accordance with the proposed parameters. GPS devices are highly functioning resilient equipment that can easily co-exist with the network proposed by Ligado.

Furthermore, a cost-benefit analysis performed by economist and former Federal Communications Commission (FCC) Commissioner Harold Furchtgott-Roth demonstrates that by taking this action, the Commission can put in place actions that will realize a net present value of present and future consumer surplus estimated at $13-$260 billion. As Commissioner Furchtgott-Roth explains, regulatory *in*action leads to delayed investment, and delayed investment results in consumer benefits forever lost. Prior Commissions have allowed these 40 megahertz of spectrum to lay fallow for too long. The United States government should recognize the consensus of industry and

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[1] *See infra* Section II.A.

scientific opinion expressed in this proceeding and put this vital mid-band spectrum to work in building our 5G and IoT future.

Issuing a Notice of Proposed Rulemaking on the shared commercial use of the 1675-1680 MHz band continues the effort by the Commission, the Administration, and Congress to ensure that the Nation's vital spectrum resources are used efficiently and benefit all Americans. That band also is an important component of the pending proposal to bring the 40 megahertz of spectrum to facilitate the transition to 5G and promote American leadership in IoT. Initiating the rulemaking process is the necessary next step that will enable the Commission to determine whether the National Oceanic and Atmospheric Administration's (NOAA) operations in the band can be safeguarded and how the interests of others can be protected using advanced communications networks.

A. Enabling Terrestrial Use of Ligado's Spectrum Will Promote America's Technology Leadership and Spark Investment in Infrastructure.

The burgeoning demand for mobile broadband has been well documented.[2] Enabling the terrestrial use of mid-band spectrum will add capacity and help wireless network providers respond to this demand. Mid-band spectrum like the spectrum in Ligado's proposal is vital to U.S. leadership in 5G because of its reliability and suitability for high-quality coverage and capacity deployment. Mid-band spectrum has better propagation characteristics for in-building penetration than very high-frequency spectrum. As the chief network officer of Verizon recently said, "Enhanced fixed and mobile broadband, low-latency services and massive IoT scale will thrive on mid-band and millimeter wave spectrum."[3] Ligado is uniquely positioned to leverage the potential of this mid-band spectrum by offering next-generation network capabilities that will be particularly attractive to "mission-critical" IoT devices. These potential capabilities include pervasive connectivity that leverages Ligado's integrated satellite and terrestrial services, ultra-reliability for improved remote monitoring or emergency response, enhanced precision location services, and highly secure transmissions.

Approving Ligado's applications would advance American spectrum leadership by clarifying property rights in 40 megahertz of spectrum, providing much needed wireless capacity, and enabling innovative 5G and IoT services.

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[2] *See Protecting and Promoting the Open Internet*, R&O on Demand, Declaratory Ruling, and Order, 30 FCC Rcd.5601, 5636 (2015).

[3] Nicola Palmer, *Unparalleled Network Leadership by Doing*, Verizon.com (Apr. 28, 2017), http://www.verizon.com/about/news/unparalleled-network-leadership-doing.

B. Ligado's Spectrum Proposal

Since its predecessor LightSquared emerged from bankruptcy in 2015, Ligado—with new owners, new management, and a new attitude—has focused on finding solutions that would enable the company to put its mid-band spectrum to the most productive use without harming adjacent band users. Ligado's current licenses include an authorization to provide ancillary terrestrial component (ATC) mobile service.[4] In 2012, a number of parties raised concerns regarding the compatibility of the then-proposed terrestrial mobile network with GPS operations in the 1559-1610 MHz band.[5] Immediately after emerging from bankruptcy in 2015 and building on years of analysis and testing, Ligado successfully reached co-existence agreements with the leading GPS manufacturers that established the parameters under which Ligado can operate its proposed network and as to which the major GPS companies have no objection. The company also conceived of an entirely new business plan, one that combines the satellite capability with a terrestrial network at reduced operating parameters and fewer towers than was conceived previously. Ligado's Advanced Satellite Terrestrial Network will be designed for machine-to-machine (M2M) communications for critical vertical industry sectors in transportation, energy, electric utility, and for public safety.

1. Ligado Proposes Reduced Power and Out of-Band-Emission Limits on ATC Spectrum.

Ligado's pending proposal aims both to resolve the previous concerns and also to promote the public interest by enabling significant additional spectrum to be used for next-generation mobile services. To this end, in its applications before the Commission, Ligado has offered a comprehensive technical compromise that will enable Ligado to proceed with the deployment of its next generation mobile network and protect other important users of neighboring spectrum.[6] These applications seek to cement into Ligado's licenses the substantial power and out-of-band emission (OOBE) reductions that the GPS companies requested and to which Ligado has agreed:

- *First*, Ligado's applications request that the FCC rescind Ligado's ability to use the 1545-1555 MHz band (under Ligado's proposal, the "upper downlink" band) for terrestrial service, thus effectively establishing a 23 megahertz "guard band" to protect GPS.

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[4] *LightSquared Subsidiary LLC Request for Modification of its Authority for an Ancillary Terrestrial Component*, Order and Authorization, 26 FCC Rcd. 566 (IB 2011).

[5] *International Bureau Invites Comment on NTIA Letter Regarding LightSquared Conditional Waiver*, Public Notice, 27 FCC Rcd. 1596, 1599 (IB 2012).

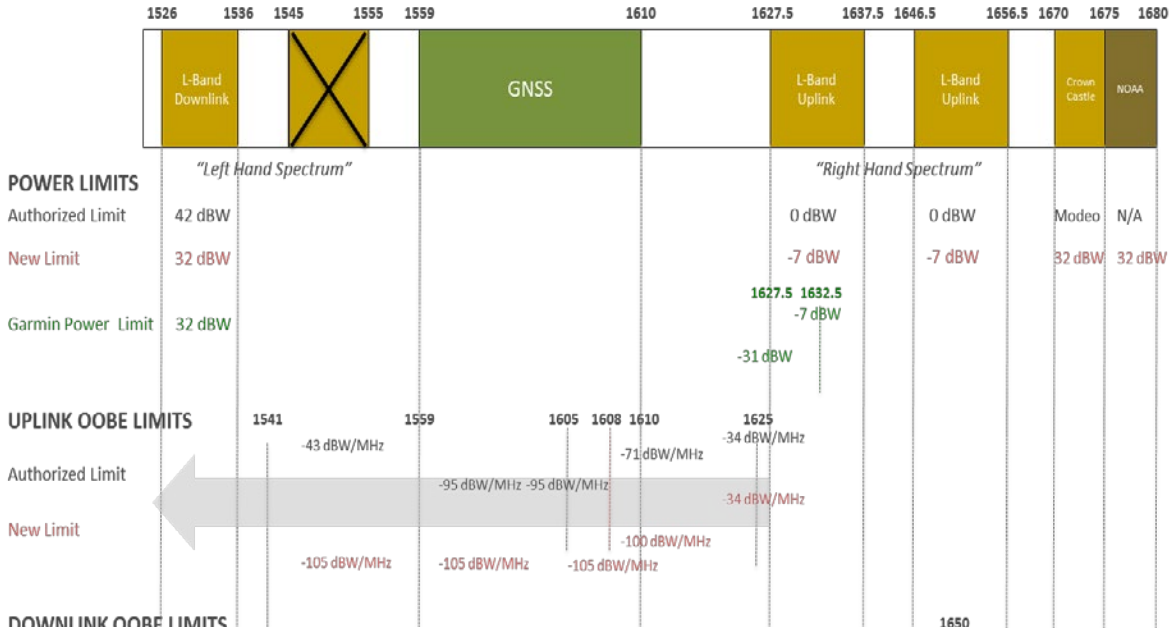
[6] *See* Letter from Gerard J. Waldron, Counsel to New LightSquared LLC, to Marlene H. Dortch, Secretary, FCC, IB Docket Nos. 12-340 and 11-109; IBFS File Nos. SAT-MOD-20120928-00160, SAT-MOD-20120928-00161, and SES-MOD-20121001-00872, at 1 (Dec. 31, 2015) (Ligado Dec. 31, 2015 Ex Parte).

- *Second*, for the three other bands relevant to Ligado's applications, Ligado has proposed a much more restrictive set of operational parameters than is currently authorized. Specifically, the applications propose reduced power levels nationwide for base stations that would operate in the 1526-1536 MHz band (under Ligado's proposal, the "lower downlink" band) and for user equipment in the 1627.5-1637.5 MHz and 1646.5-1656.5 MHz portions of the band (the "lower uplink" and "upper uplink" bands, respectively).

- *Third*, to further protect certified aviation GPS devices, Ligado's applications propose that the company's license be conditioned on power limits in the 1526-1536 MHz band across the country as necessary to achieve compatibility with current and future Minimum Operational Performance Standards that are incorporated into an active Technical Standard Order from the Federal Aviation Administration (FAA).[7]

Figure 1 illustrates the proposed changes to power level and OOBE limits that are contained in the applications.

Figure 1. Technical Operating Parameters Specified in Ligado's Petitions



Note: Ligado's applications also include narrowband limits not depicted here.

[7] *See* Modification Applications, Description of Proposed Modification, at 10-12.

The agreements with GPS companies have led to extraordinary changes in Ligado's proposal in which Ligado has agreed to relinquish one 10 megahertz band of spectrum and operate at dramatically reduced power and OOBE limits on its other bands. Specifically, Ligado has agreed to operate at power limits that are lower than its current licenses authorize *by a factor of 10 times for the downlink and a factor of five times for the uplinks,* and for the first five years, by as much as a factor of 1,250 times for part of the lower uplink closest to the GPS band. For operations from the uplink bands into the GPS spectrum band, Ligado also has agreed to operate with OOBE limits that are lower than what is currently authorized *by a factor that ranges from 10 times to 800 times*. In short, Ligado's current proposal reflects a fundamental shift from the previous LightSquared proposal because it protects, rather than puts at risk, GPS.

2. Ligado's Proposal Requests That the FCC Allocate the 1675-1680 MHz Band for Shared Use.

As part of its 40 megahertz spectrum plan, Ligado also requested that the Commission initiate a rulemaking to reallocate the 1675-1680 MHz band to shared commercial use. The record shows that this proposal would have no impact on NOAA operations. Besides weather balloons, which are being relocated to 400 MHz as part of the AWS-3 auction, NOAA plans to operate only about twenty-four earth stations nationwide that will be within or immediately adjacent to the 1675-1680 MHz band. Moreover, by 2021, due to the aforementioned relocation of weather balloon activity and retirement of older Geostationary Operational Environmental Satellites satellites, NOAA will use only 0.3 MHz of this 5 megahertz band. As explained below, the 1675-1680 MHz band can be unlocked for wireless broadband while at the same time ensuring that neither NOAA nor any other entity that accesses NOAA's weather data suffers harm.

Allocating this band for shared commercial use would not harm NOAA or the approximately 100 unlicensed, non-governmental users who "listen in" on the band. A study by an independent consulting firm selected in consultation with NOAA demonstrates that NOAA's operations in the 1675-1680 MHz band can be protected through the establishment of geographic protection zones.[8] Ligado's proposed use of the band would respect these protection zones.

[8] This engineering analysis was prepared in 2014 by Alion Science and Technology (Alion), a company chosen based on NOAA's recommendation. The Alion report identifies and sets out the specific parameters for effective protection of NOAA's earth stations. *See* Alion Science and Technology, *Assessment of the Potential for LightSquared Broadband Base Stations in the 1670-1680 MHz Band To Interfere with Select NOAA Legacy Ground Locations* (Feb. 2014) ("Alion Task 2 Report"), *filed as attachment to* Letter from Jeff Carlisle, Executive Vice President for Regulatory Affairs and Public Policy, LightSquared Subsidiary LLC, to Marlene H. Dortch, Secretary, FCC, RM-11681; IB Docket No. 12-340; IBFS File Nos. SAT-MOD-20120928-00160, SAT-MOD-201220928-00161, SES-MOD-20121001-00872 (Apr. 14, 2014).

Additionally, to resolve any potential impact to the small number of non-NOAA users, Ligado proposed that the Commission require the new commercial licensee of 1675-1680 MHz to provide the NOAA data using alternative, proven 21st Century technology. Making use of readily available and widely deployed technological solutions, Ligado developed a plan, which it presented in detail in August 2016, to deliver the data via a cloud- and fiber-based content delivery network (CDN) using "push" technology. [9] Last summer, Ligado purchased a NOAA-compatible satellite receiver and dish system similar to those used by all non-NOAA users and developed a CDN, using an established cloud service provider, to deliver NOAA's weather data through the cloud and via fiber optic links.[10] Ligado's CDN is now operational and has been delivering this data to George Mason University and others. After several months of operating the system, Ligado can report that the CDN is running according to the August 2016 plan and is delivering to George Mason University the same data NOAA currently provides in a timely and highly reliable manner.[11]

On May 23, 2017, the President's Budget not only endorsed again the reallocation of the 1675-1680 MHz band to shared commercial use, it expressly endorsed the protection zones and content delivery network proposal outlined above.[12]

II. Terrestrial Use of Ligado's Mid-Band Spectrum Will Not Harm GPS Devices.

Ligado's applications propose substantially reduced power and OOBE limits for its network in order to ensure Ligado's operations would not harm GPS devices. Ligado developed these operating parameters in cooperation with leading GPS device manufacturers Garmin, Deere, and Trimble to determine how Ligado's mid-band spectrum could be used more productively and not interfere with GPS. As noted above, those proposed limits are reflected in co-existence agreements that Ligado reached with these major GPS device manufacturers.

Independent tests conducted by Ligado, involving nearly 5,000 lab hours, confirm that Ligado's operations would not harm GPS devices. First, Roberson and Associates (RAA) spent nine months researching and testing how Ligado's terrestrial deployment would affect the performance of 27 GPS devices, across four different categories of devices, at various power levels. RAA concluded that GPS devices in realistic use cases would either be generally unaffected by Ligado's proposed deployment, or, if affected, could be retro-fitted in an economical manner so they are

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[9] *See* Reply Comments of Ligado Networks LLC, RM-11681, at 23-26 (Aug. 11, 2016).

[10] *See id.*

[11] *See* Letter from Gerard J. Waldron, Counsel, Ligado Networks, to Marlene H. Dortch, Secretary, FCC, RM 11-681 (Mar. 1, 2017).

[12] *See* Office of Mgmt. & Budget, Exec. Office of the President, Budget of the United States Government, Fiscal Year 2018 (2017). *See also* FCC, Fiscal Year 2018 Budget Estimates to Congress (May 2017) at 9.

unaffected. Second, more recently the National Advanced Spectrum and Communications Test Network (NASCTN) conducted extremely rigorous testing—including thousands of hours in the lab—regarding the location and timing accuracy of GPS devices when exposed to the potential wireless broadband operations proposed by Ligado. NASCTN's results, published in February 2017, affirm the conclusion of the major GPS companies and are consistent with RAA's conclusions: the network parameters reflected in the GPS manufacturers' co-existence agreements and in Ligado's applications will not harm the performance of GPS devices.

Ligado's proposal also asked the Commission to condition the license in a manner that will protect certified aviation GPS devices to the satisfaction of the FAA. For more than a year, Ligado has worked closely with the FAA to develop a model that will define the appropriate power limit for each individual site. These additional parameters would set a more stringent restriction on power limits in the 1526-1536 MHz downlink band.

A. Ligado Worked with the Major GPS Device Manufacturers to Develop Its Spectrum Proposal and Ensure Co-Existence.

All of the major GPS companies are satisfied that their devices can co-exist with Ligado's proposed operations, and that consensus is reflected in the docket. Shortly following its emergence from bankruptcy, Ligado reached separate understandings with three of the leading GPS device companies: Deere, Garmin, and Trimble.[13] Each of these agreements sets forth the operating parameters under which Ligado could operate without objection from the relevant GPS device manufacturer.

Specifically, in their respective agreements:

- Deere and Garmin agreed that they will not object to Ligado's terrestrial deployment in three of the four bands licensed to Ligado—the 1526-1536 MHz,

[13] *See* Letter from Gerard J. Waldron, Counsel to New LightSquared LLC, to Marlene H. Dortch, Secretary, FCC, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SAT-MOD-20101118-00239; SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; SES-RWL-20110908-01047; SES-MOD-20141030-00835, at 4 (Dec. 8, 2015); Letter from Gerard J. Waldron, Counsel to New LightSquared LLC, to Marlene H. Dortch, Secretary, FCC, IB Docket No. 12- 340; IB Docket No. 11-109; IBFS File Nos. SAT-MOD-20101118-00239; SAT-MOD-20120928- 00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; SES-RWL-20110908-01047; SES-MOD-20141030-00835, at 25 (Dec. 17, 2015); Letter from Gerard J. Waldron, Counsel to New LightSquared LLC, to Marlene H. Dortch, Secretary, FCC, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SES-MOD- 20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091, at 4, 7, 19 (Feb. 3, 2016).

1627.5-1637.5 MHz, and 1646.5-1656.5 MHz frequency bands—as long as Ligado operates within certain power and OOBE limits.[14]

- Trimble also agreed not to object to Ligado's proposed operations in two of those three bands: the 1627.5-1637.5 MHz and 1646.5-1656.5 MHz frequency bands. Regarding operations in the lower downlink band (1526-1536 MHz), the Trimble agreement allows for further analysis of terrestrial use of that band.

The specifications set forth in these three agreements therefore determined the parameters under which Ligado now seeks to operate.

These three companies are industry leaders in every sense. Garmin supplies 84 percent of the personal navigation device (PND) market, the largest subset of devices in the consumer-facing general location and navigation (GLN) device market.[15] In the high-precision GPS device market, Trimble and Deere play an equally important role. Together, they represent 51 percent of high-precision device sales.[16]

Each of the three GPS companies determined that its respective agreement with Ligado established the particular parameters it needs for the continued successful operation of its own GPS devices. These agreements, and thus the resulting proposal set forth in Ligado's applications, reflect the distinct needs of each company's devices, use cases, and market share.

Moreover, the collective result of the discussions and agreements constitutes a comprehensive solution for the entire GPS industry. Although each of Deere, Garmin, and Trimble has particular operational needs, addressing the needs of those three device manufacturers goes a long way toward addressing the needs of the GPS industry as a whole because, aside from cellular devices (which have been shown to be resilient to the operating parameters proposed by Ligado), the receiver designs used by Deere, Garmin, and Trimble are also used by, and feed into, the larger GPS ecosystem and supply chain.[17] The operating parameters set forth in the applications therefore will ensure that the broader consumer GPS industry will be protected.

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[14] The Garmin agreement does not address potential interference concerns relating to certified aviation devices. *See infra* Section II.C.

[15] *See* Coleman Bazelon, *Putting Spectrum to Work: Sharing Between Ligado Networks and Its GPS Neighbors*, at app'x 1 tbls. 5 & 9 (May 23, 2016), *available at* http://licensing.fcc.gov/myibfs/download.do?attachment_key=1136780 ("Bazelon Report").

[16] *See id.* at app'x 1 tbl. 9.

[17] *See id.* at 31; Letter from Gerard J. Waldron, Counsel to Ligado Networks LLC, to Marlene S. Dortch, Secretary, FCC, RM-11681, IB Docket No. 12-340; IB Docket No. 11-109; IBFS File Nos. SES-MOD-20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091, Declaration of Bill Alberth at 2 ¶ 6 (Feb. 11, 2016).

After reaching agreements with Garmin, Deere, and Trimble, Ligado continued its outreach to and cooperation with GPS manufacturers. In the summer and fall of 2016, two leading manufacturers of high precision devices, NovAtel and Topcon, also agreed that Ligado has addressed their concerns and filed in support of Ligado's applications, further confirming that Ligado's proposed operations will not harm GPS devices.[18] Thus the record in this docket is clear: it reflects that GPS companies are satisfied that Ligado's proposed operations will not cause their customers' devices to experience harm.

B. Extensive Testing Has Verified That GPS Devices Will Not Be Harmed.

The Commission's Public Notice seeking comment on Ligado's modification applications asked for "specific comment on whether there remain any unresolved concerns of potential harmful interference to GPS receivers and devices should Ligado operate a terrestrial mobile network on the [designated] frequencies in accordance with the operational parameters in the Applications that reflect the technical parameters set forth in the [GPS] agreements."[19] The Commission requested "such commenters supply specific relevant technical information about affected GPS receivers (e.g., receiver category, receiver bandwidth) and their performance or functioning (e.g., break lock, loss of tracking, specific effects on location and timing accuracy) that support their assertion that additional measures would be necessary to resolve remaining concerns of potential harmful interference should Ligado operate a terrestrial mobile network in accordance with the specified set of technical parameters proposed."[20]

Ligado answered this request for "specific relevant technical information" by submitting extensive testing by Roberson and Associates and also by entering into a Cooperative Research and Development Agreement (CRADA) with the world-renowned spectrum scientists at the National Institute of Standards and Technology (NIST) who staff NASCTN, the joint spectrum testing operation of the Departments of Commerce and Defense. As explained below and in detail in Appendix A, these tests clearly establish that GPS devices will experience no harmful interference or readily can be protected from it. It bears emphasis that the Commission's record contains no other technical information analyzing the effect of Ligado's proposed operations on GPS. It

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[18] *See* Letter from Doug Smith, CEO, Ligado Networks LLC, and Ivan Di Federico, Chief Strategy Officer, Topcon Positioning Systems, Inc., to Marlene S. Dortch, Secretary, FCC, IB Docket No. 11-109 (Nov. 29, 2016), *available at* https://ecfsapi.fcc.gov/file/12062186417510/FCC%20Letter%20TopconLigado.pdf ("Topcon-Ligado Letter"); Letter from Doug Smith, Ligado Networks LLC, and Michael Ritter, NovAtel Inc., to Marlene Dortch, Secretary, FCC, IB Docket No. 11-109 (June 27, 2016), *available at* https://ecfsapi.fcc.gov/file/10628411910166/NovAtel-Ligado%20Letter.pdf ("NovAtel-Ligado Letter").

[19] *See Comment Sought on Ligado's Modification Applications,* Public Notice, 31 FCC Rcd. 3802, 3809 (2016).

[20] *Id.*

also is important to note these are the only studies that have analyzed the *actual performance* of GPS devices when exposed to LTE signals at the power levels proposed by Ligado and in Ligado's proposed bands.

Opponents of terrestrial mid-band deployments who continue to claim that Ligado's proposal could harm GPS devices have not submitted any technical information supporting such claims. These claims have been laid to rest by the two rigorous tests discussed above. Other critics seek to avoid the question of *harmful* interference and have instead insisted that Ligado's proposed network should be blocked if it could cause *any* interference, even that which does not have any impact on performance. In particular, some critics have argued that mid-band wireless signals could cause a 1 dB decrease in certain GPS devices' reported Carrier-to-Noise-Density ratio (C/N_0). But both theoretical analyses and empirical testing have demonstrated that the "1 dB" metric is inaccurately and inconsistently measured; is arbitrary; and represents a flawed proxy because it does not translate to any noticeable impact on *actual* device performance.

Appendix A, attached to this paper, explores in detail the various tests by RAA, DOT, and NASCTN, and discusses how harmful interference should be assessed. In sum, all of the relevant data demonstrate that GPS devices can co-exist with Ligado's proposed network. Protecting GPS devices ***and*** enabling the use of 40 megahertz of mid-band spectrum is the win-win that will enable America to unlock the economic and technological benefits of this vital mid-band spectrum.

C. Ligado's Proposal Will Protect Certified Aviation GPS Devices.

In its December 2015 applications, Ligado requested that the FCC modify its licenses to ensure that Ligado's operations protect certified aviation GPS receivers. For more than a year since its FCC applications were filed, Ligado has worked diligently with the FAA and the agency's advisory panels to develop a mechanism to do just that. Ligado analyzed the implications for both fixed-wing and rotorcraft aircraft using certified aviation GPS receivers in a number of scenarios, including takeoff and landing, instrument approach procedures, en route navigation, and complementary services that rely on a GPS input (such as ADS-B and TAWS/HTAWS), to determine the best way to conform with the Minimum Operational Performance Standards (MOPS) that are incorporated into an active FAA Technical Standard Order (TSO). Ligado and the FAA determined that helicopter uses were the limiting case for power determinations because federal aviation regulations permit helicopters to operate in much closer proximity to a structure, including transmit antennas, than fixed-wing aircraft.

To determine the actual power of an individual Ligado antenna, and recognizing the relevance of characteristics like height and downtilt that may vary from tower to tower, Ligado worked with the FAA to develop a multi-step process. First, using established FAA two-ray propagation models, Ligado determined the received power for a helicopter operating in level and banked flight at all points along the surface of a cylinder of airspace immediately adjacent to a Ligado antenna, extending 250 feet

laterally from the antenna, and from the ground to 30 feet above the antenna (the "standoff cylinder"). Using the point of highest potential interference from a Ligado transmitter, the model determines the reduction in antenna power necessary to comply with the MOPS mask. Second, to account for the effect of a network of antennas, Ligado examined the aggregate effect of towers placed at the closest possible location (*i.e.*, the minimum intersite distance) and further reduced the power to account for the aggregate effect of multiple antennas. Third, the model then reduces the power further to account for the rare probability of fluctuations in instantaneous power, as provided in the FAA models.

Finally, to ensure that Ligado's operations will not interfere with operations that rely on certified aviation GPS receivers for instrument flight, including approach and departure from airports, Ligado has committed not to install an antenna in a location where any portion of the standoff cylinder would enter the obstacle clearance surface.

In its analysis, Ligado relied on existing FAA methodologies, which incorporate conservative assumptions to protect aviation safety. In September 2016, the results of Ligado's extensive work with the FAA were submitted to the agency's advisory panel, the RTCA, and its subsidiary working groups and committees. The RTCA provided comments to the FAA in December 2016. The company's discussions with the FAA are now complete and have produced a detailed, workable approach to ensuring compliance with all applicable FAA standards and the protection of certified aviation GPS devices. Appendix B discusses this methodology in more detail and describes key attributes that should be incorporated into an FCC license condition to implement these requirements.

III. The 1675-1680 MHz Band Can Be Shared by Commercial Users with NOAA.

The final component of Ligado's spectrum proposal is its petition to allow for shared commercial use of the 1675-1680 MHz band of nationwide spectrum that is currently used exclusively by NOAA.

A. Exclusive Use of the 1675-1680 MHz Band Is Inefficient and Fails to Benefit the Public Fully.

The 1675-1680 MHz band is a critical element in unlocking the next wave of communications technology. But this potential can be realized only if the band is allocated to shared commercial use. Continuing to restrict the band to NOAA's exclusive use unnecessarily stunts this potential.

Mid-band spectrum is an essential element for the development of wireless broadband growth.[21] Its characteristics can enable an order of magnitude increase in spectrum efficiency. Specifically, access to more mid-band spectrum can enable the delivery of advanced connectivity services and accelerate the transition to 5G. It can also enable a network optimized for IoT use cases, allowing new connected devices to develop and evolve. Yet under the status quo, five megahertz of spectrum is reserved on a nationwide basis for use by only a small number of earth stations—meaning the band essentially lies fallow across the overwhelming majority of the country. The Commission has made clear that today's spectrum environment requires the elimination of such inefficiencies, not their perpetuation.[22] Moreover, the goal of reallocating this band for shared use has been endorsed both by Congress—most recently in the Omnibus spending bill passed in April—and by the Administration's Budget in May.[23] It has also been the subject of multiple letters of support from Members of Congress and others.[24] Accordingly, the Commission should issue an NPRM to explore maximizing this band's potential by allocating the 1675-1680 MHz band for shared commercial use. As explained below, in a shared use framework, both NOAA and non-NOAA users will remain fully protected.

B. NOAA's Use of Spectrum Can Be Fully Protected.

It has been demonstrated in this proceeding that sharing the 1675-1680 MHz band with commercial services will not harm NOAA's operations. NOAA's use of this band consists of two key components: NOAA's radiosonde (weather balloon instrument) operations and NOAA's operations involving current and next generation Geostationary Operational Environmental Satellites (GOES and GOES-R, respectively) that occupy a portion of this and adjacent bands. Both components can remain fully protected if the band is shared with a commercial wireless network.

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[21] *See supra* note 3 (Verizon's chief network officer stating mobile broadband and IoT will "thrive on mid-band and millimeter wave spectrum").

[22] *See, e.g.*, *In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, 31 FCC Rcd. 5011 (2016), at ¶ 52 (finding that shared use of the 3.5 GHz band fulfills the FCC's statutory mandate because it "promotes efficient and intensive use" of the spectrum and "allows for the development and rapid deployment of new technologies, products, and services for the benefit of the public") (internal quotations omitted).

[23] *See* Consolidated Appropriation Act, 2017, Pub. L. No. 115-31 (2017); Office of Mgmt. & Budget, Exec. Office of the President, Budget of the United States Government, Fiscal Year 2018 (2017). Indeed, Congress has repeatedly and consistently called for shared commercial use of this band, as did the previous Administration. *See* Office of Mgmt. & Budget, Exec. Office of the President, Budget of the United States Government, Fiscal Year 2017 (2016), at 220; Office of Mgmt. & Budget, Exec. Office of the President, Budget of the United States Government, Fiscal Year 2016 (2015), at 215; Office of Mgmt. & Budget, Exec. Office of the President, Budget of the United States Government, Fiscal Year 2015 (2014), at 199; Office of Mgmt. & Budget, Exec. Office of the President, Budget of the United States Government, Fiscal Year 2014 (2013), at 228-229.

[24] *See, e.g.*, Letter from Gerald E. Connolly, Member of Congress, Virginia, 11th District to The Hon. Tom Wheeler, Chairman, FCC (Apr. 20, 2016), *available at* https://ecfsapi.fcc.gov/file/60001692712.pdf.

Appendix C summarizes NOAA's various activities and how they rely on, or in most cases do *not* rely on, the 1675-1680 MHz band. It also identifies the limited ways in which shared commercial use would affect non-NOAA users.

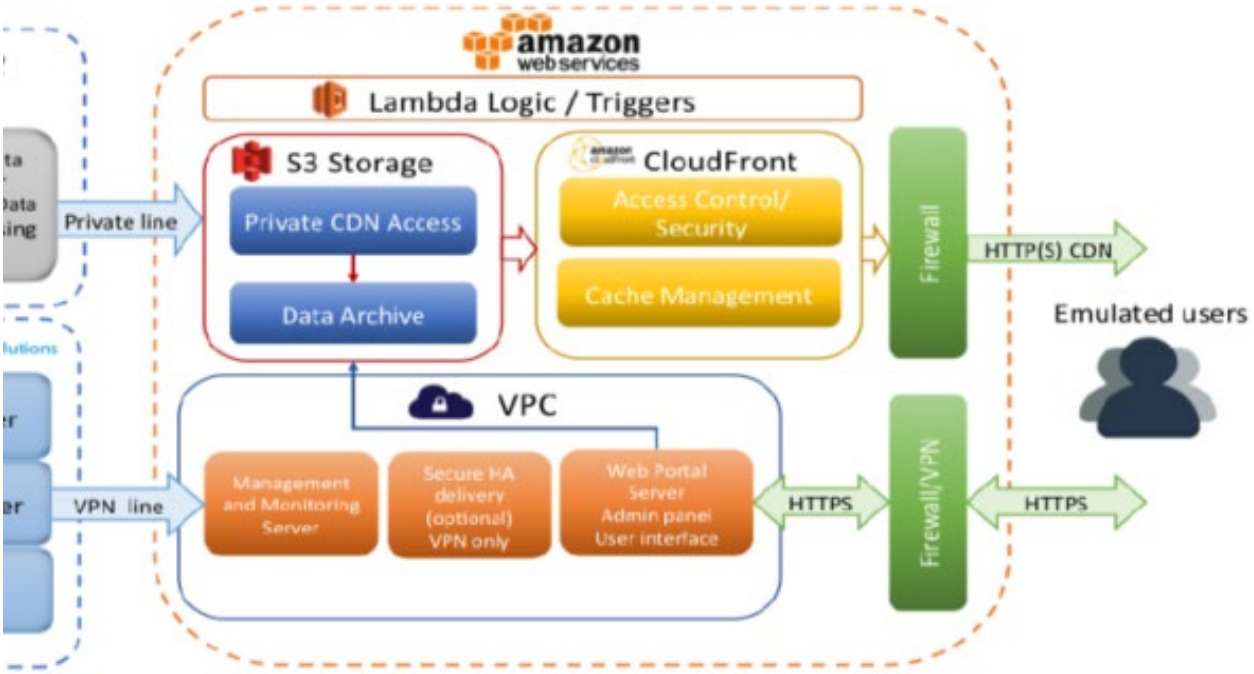
C. Non-NOAA Users Can Access Data Through Delivery Networks.

A limited number of non-NOAA users currently "listen in" on the services adjacent to the 1675-1680 MHz band. To be clear, these entities are not licensed users in this band; rather, they are third-party, unlicensed beneficiaries of the spectrum allocation to NOAA. To address any potential effects to these non-NOAA users, Ligado has provided a detailed proposal for, and has begun a demonstration of, a content delivery network (CDN) to provide these users with a new—and in some ways better—method of accessing NOAA data.

Specifically, Ligado has proposed that the Commission condition grant of the 1675-1680 MHz license on the licensee developing (and if desired by NOAA, operating and funding) a CDN. Developing a CDN would thus be a prerequisite to the use of the spectrum.

The CDN would work by gathering NOAA data at a designated receive point. The CDN would then immediately push it to a widely-distributed set of servers. Non-NOAA users currently have to wait for NOAA data to be uplinked to GOES-R and then receive it via downlink. Since the CDN would ideally transmit the data directly from the receive point, non-NOAA users of the CDN would access data *even more quickly than they do now*. CDN users would also be able to receive more weather products than they currently receive. NOAA produces more weather products than its uplink can transmit. By connecting directly to the receive facility, the CDN would be able to provide all of these products should NOAA choose to include them. End users could access the CDN over the public Internet or via a direct fiber connection, depending on each user's needs.

Figure 2. Ligado's Proposed Content Delivery Network



The CDN would thus provide this speedier, more comprehensive access while lowering the practical and cost barriers—currently, an estimated $130,000 just to begin receiving data—that have prevented other parties from accessing this data. The CDN approach is consistent with how leading financial institutions, high-tech companies, high-value content companies, and virtually every other sector of the modern economy delivers high-value content today.[25] Given the inherent logic of using the vast fiber optic and cloud resources in the country to deliver this vital information, it is not surprising that NOAA itself has been exploring non-satellite delivery of weather information.[26] NOAA's lack of support for Ligado's proposed CDN unfairly denies this development to the entire weather community.

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[25] *See id.*; *see also* "FINRA Case Study," AWS.Amazon.com, https://aws.amazon.com/solutions/case-studies/finra/ (last visited June 5, 2016) (noting that the Financial Industry Regulatory Authority, one of the largest independent securities regulators in the U.S., relies on Amazon Web Services' CDN platform "to capture, analyze, and store a daily influx of 75 billion records"; "Met Office," Akamai.com, https://www.akamai.com/us/en/our-customers/customer-stories-the-met-office.jsp (last visited June 5, 2016) (noting that the website of the UK Met Office, which relies on its website as "a key delivery channel" for its weather services and interactive content, relies on Akamai's CDN platform and other cloud services).

[26] *See* Luis Cano, *NOAA NWS Integrated Dissemination Program* (IDP) (Mar. 21, 2014), at 6, *available at* http://www.cio.noaa.gov/NOAALink/docs/IDP_Overview.pdf.

For its part, Ligado already has established and begun operating the above-described CDN. On December 15, 2016, Ligado announced a new partnership with George Mason University, Virginia's largest public research university, to provide public access to weather and atmospheric data through Ligado's CDN. This partnership has enabled a prominent state research institution to receive NOAA's data—which Ligado is providing to GMU for free—and compare the CDN distribution methodology to NOAA's current weather data distribution. The comparative analysis will include assessing the relative speed and reliability to users across the country. The Ligado/GMU joint effort also will include reviewing and improving the accuracy of weather forecasting models and methods for the advanced detection of meteorological conditions, such as tornadoes and dense ground fog. GMU's weather researchers anticipate developing new information extraction tools that would be made available to the public, thus bringing the benefit of NOAA's rich trove of data to the public—without a $130,000 expenditure.

IV. Iridium's Attempt to Thwart Competition with Faulty Interference Claims Should Be Rejected.

Iridium's filings in this proceeding assert (a) that it has no concerns with three of the bands (1526-1536 MHz, 1646.5-1656.5 MHz, and 1670-1680 MHz), and (b) LTE operations in the fourth band (1627.5-1637.5 MHz) may cause harmful interference to Iridium's operations.[27] Iridium's engineering analysis is flawed for reasons that we have explained previously, but most egregiously, Iridium's analysis remains willfully blind to basic, well-accepted characteristics of LTE technology, and instead relies on an unrealistic worst-case analysis to inflate the interference risk posed to Iridium by Ligado's proposed ATC operations. This distorted analysis obfuscates some fundamental truths.

First, while Iridium claims that satellite and terrestrial services do not mix, the truth is that it has chosen to operate downlink services in a spectrum neighborhood primarily allocated for uplink operations. As a consequence, Iridium finds itself in perpetual conflict with its spectrum neighbors.[28] In this matter, Iridium is simply

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[27] *See, e.g.*, Letter from Letter from Bryan N. Tramont, Counsel to Iridium Communications, Inc., to Marlene H. Dortch, Secretary, FCC, IB Docket No. 11-109 *et al.* (Sept. 1, 2016).

[28] *See, e.g.*, *Iridium Constellation LLC*, Mem. Op. & Order, 28 FCC Rcd. 964, 966 (2013) (emphasizing, in response to "concern that Iridium's request for AMS(R)S authority was a ploy to upgrade the status of Iridium's downlink operations from secondary to super-primary," that grant "does not and should not be construed to require new restrictions on already licensed operations of earth stations in adjacent frequency bands"); *Spectrum & Service Rules for Ancillary Terrestrial Components in the 1.612.4 GHz Big LEO Bands*, Second Order on Recon., Second R&O, and NPRM, 22 FCC Rcd. 19733, 19740-42 (2007) (concluding, in accordance with Globalstar analysis and contrary to Iridium, "that fully-loaded TDMA and CDMA systems cannot share spectrum in a co-frequency, co-coverage manner without generally undesirable operational limitations"); *Review of the Spectrum Sharing Plan Among Non-Geostationary Satellite Orbit Mobile Satellite Service Systems in the 1.6/2.4 GHz Bands*, R&O, Fourth R&O, and FNPRM, 19 FCC Rcd. 13356, 13371-78 (2004) (summarizing opposition to Iridium proposal for revised L-band band plan and rejecting Iridium arguments for "spectrum parity").

attempting to relitigate the FCC's *2003 ATC Order*, which put Iridium on notice that it would be required to tolerate much less restrictive OOBE limits than the one currently proposed by Ligado.[29] *See* Appendix D.

Second, if Iridium's assertions to its customers are to be believed, Iridium is able to operate effectively today in the face of existing interference that is *far greater than* any interference Iridium would experience from Ligado's ATC operations. That leads one to question Iridium's motivation in opposing Ligado's proposal when the result will be a neighbor operating an LTE system with handsets at *0.2 watts instead of an authorized satellite network operating at 1 to 2000 watts.*

Third, competition from Ligado, with its advanced satellite-terrestrial network, would interfere not with Iridium's devices but with Iridium's business plans—to expand from a niche voice service into the growing machine-to-machine market. Unfortunately for Iridium, the Communications Act provides no protection to any licensee from such marketplace "interference." Nor should the Commission tolerate Iridium's attempt to effectively appropriate to itself spectrum that has been licensed to Ligado and that is ready to be used for delivery of advanced terrestrial-satellite services to promote 5G and machine-to-machine communications at the heart of the IoT.

Accordingly, for the reasons set forth in Ligado's previous filings on this matter, the Commission should reject Iridium's claims that Ligado's proposed ATC service in the lower uplink would cause harmful interference to Iridium.

V. Conclusion

The record is clear that approving Ligado's applications would provide enormous public benefits. Approval would put 40 megahertz of mid-band spectrum to use to develop a next generation network, spark technologic innovation, and alleviate increasing spectrum demands. Granting Ligado's applications would also clarify and enhance property rights in spectrum, thus spurring greater economic activity and growth, providing billions of dollars of consumer benefits, creating thousands of jobs, and advancing continued American leadership in spectrum policy—including in promoting the development of 5G and IoT. The Commission has ample evidence to act on the pending applications and should do so promptly to promote hundreds of millions of dollars in private sector investment, generate thousands of jobs, and advance U.S. leadership in 5G and IoT.

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[29] *See Flexibility for Delivery of Communications by Mobile Satellite Providers in the 2 GHz Band, the L-Band, and the 1.6/2.4 GHz Band*, 18 FCC Rcd. 1962, at ¶ 178 (2003).

APPENDIX A
Extensive Testing Has Verified That GPS Devices Will Not Be Harmed

With nearly 5,000 lab hours spent by the NASCTN and RAA teams, the spectrum being considered in the pending license modification applications may be the most extensively tested spectrum ever. This Appendix summarizes those tests and the data they reported.

RAA Testing. RAA's test results, which have been submitted into the record, show the resilience of 27 devices across four categories.[30] The data verifies that the operational parameters agreed to by Ligado and the GPS device manufacturers would protect GPS operations. In particular, the RAA data confirm that the parameters set forth in the agreements with GPS companies ensure that consumers using GPS-equipped devices such as smartphones and general navigation devices can be confident that their devices will continue to function properly if Ligado uses its spectrum for terrestrial wireless broadband consistent with the power limits requested in Ligado's applications. The RAA data further confirm that, for certain high-precision or industrial uses, many GPS devices are designed in such a way that they can co-exist with Ligado's proposed network. Other devices will not be used near any network facility or can be retrofitted cost effectively well before Ligado's network would begin operation.[31]

The RAA study was designed to measure what, if any, effect Ligado's proposed network operations would have on the ability of GPS devices in various market segments to accurately provide position measurements: that is, to accurately tell the users of the device where they are. RAA's analysis focused on evaluating the results in the context of the power limits and OOBE limits proposed in Ligado's applications.

RAA ultimately selected for testing General Location and Navigation (GLN), cellular, and high-precision devices, as well as a non-certified aviation device. Careful consideration went into RAA's determination of which devices to select for testing. RAA reviewed the various categories that comprise the GPS receiver market. The largest of these categories—based on the number of devices installed in the market—is cellular handsets, followed by GLN devices.[32] High-precision devices represent a much smaller segment of the GPS market, although high-precision devices can be more vulnerable to interference since many of these devices have relatively wide RF front-end bandwidths

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[30] *See* Roberson and Associates, LLC, "Results of GPS and Adjacent Band Co-Existence Study," IB Docket No. 11-109, at 2 (May 11, 2016) ("RAA Report"), *available at* https://ecfsapi.fcc.gov/file/60001841466.pdf.

[31] *See* Bazelon Report, *supra* note 15, at 30.

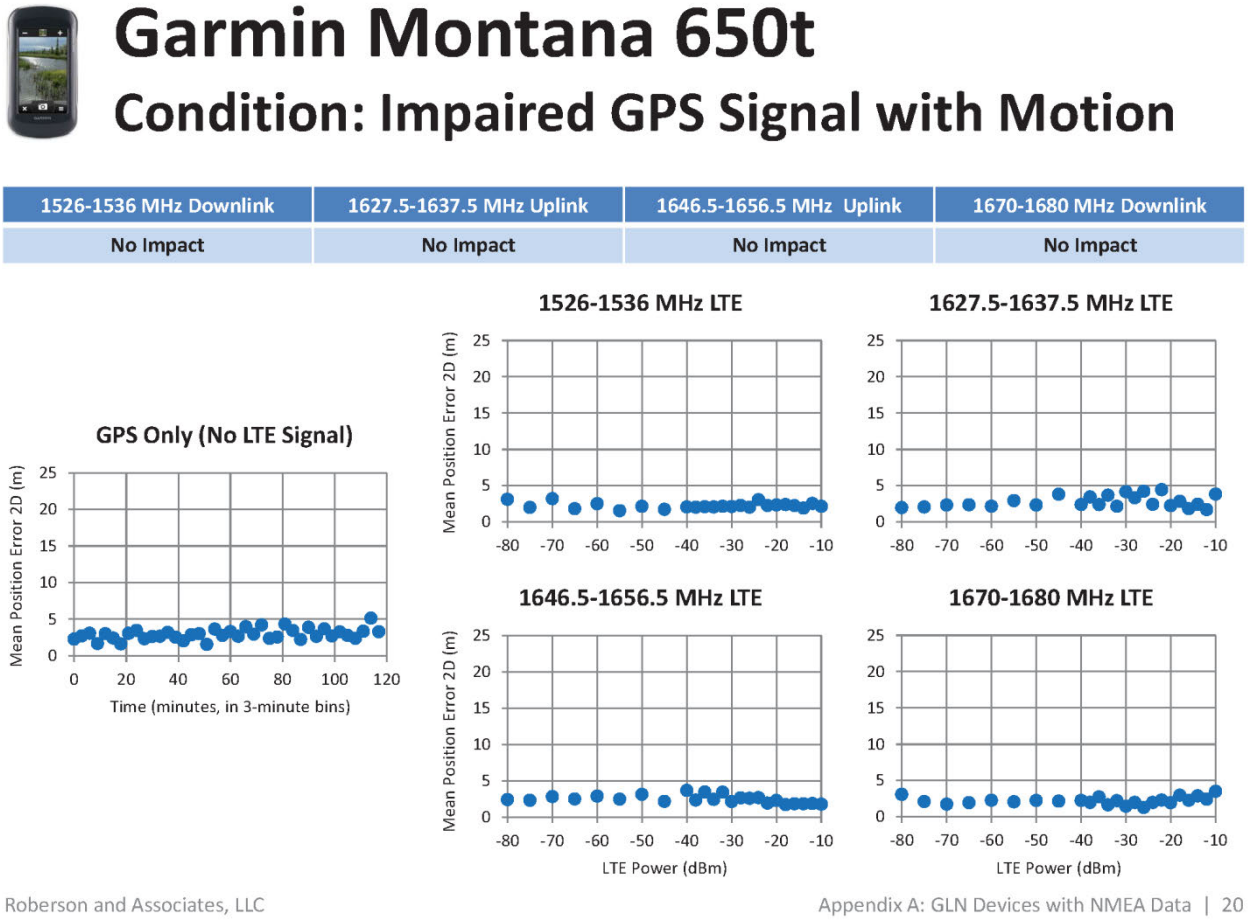
[32] *See id.* at 26 fig. 6.

as they have been designed to receive an MSS augmentation signal in the 1525-1559 MHz MSS band.[33]

RAA selected devices produced by leading manufacturers from which it was feasible to access usable data. RAA also considered that manufacturers in the GPS consumer device industry (other than cellular handset manufacturers) largely share a common supply chain and use similar or identical GPS consumer device component parts.

RAA first tested a device's baseline ability to accurately measure its position in the absence of any of Ligado's proposed signals by comparing the device's reported

Figure 3. Example of RAA Test Data for a GLN Device



[33] These wide RF front-end receivers are no longer necessary since Ligado has committed to provide this augmentation signal in the 1555 MHz band and higher, which provides sufficient separation between any MSS augmentation and any terrestrial use of the L-band.

position with the device's "true" position. RAA then compared the device's baseline performance with the device's performance in the presence of wireless network signals under the parameters Ligado has proposed in its applications. For example, *Figure 3* illustrates RAA's test results for one GLN device, Garmin's Montana 650t, under one test condition, "Impaired GPS Signal with Motion."

RAA's testing found the following about the classes of GPS devices:

- **Consumer Devices:** RAA completed testing on a total of 15 consumer devices, produced by six manufacturers.
    - ***Smartphones and Tablets*:** RAA tested three cellular devices (one tablet and two smartphones), which all maintained their baseline GPS position accuracy in the presence of Ligado's proposed operations.[34]
    - ***General Location and Navigation*:** All 12 GLN devices tested—representing five manufacturers—maintained their baseline GPS position accuracy in the presence of Ligado's proposed operations under "Open Sky" conditions. Even when presented with GPS signals 16 times weaker than the levels a GPS receiver would experience outdoors with an unobstructed view of the sky, only one of these 12 devices showed any effect from Ligado's proposed operations—an effect that appeared in only one of the four proposed Ligado bands, only when the device was in motion, and at power levels that will occur with extremely low probability.
- **Industrial Devices (High-Precision):** RAA completed testing on a total of 11 high-precision devices, produced by four different manufacturers.
    - Two manufacturers offer devices that, in stock condition, maintain their baseline GPS position accuracy in the presence of Ligado's proposed operations. Four of the 11 tested devices are in this category.
    - One of these manufacturers also offers devices that, although they show an impact from Ligado's proposed operations in stock condition, showed no such impact when the device's stock antenna was replaced with a filtered antenna. Three of the 11 tested devices are in this category.
    - Although one device, NovAtel's SMART6-L, showed some impact when using its stock internal antenna, NovAtel supports Ligado's applications. [35]

[34] RAA also compared the performance of the Samsung Galaxy S6 with its predecessor, the S5, and found that these cellular GPS devices' performance (which already is highly robust) continues to improve over time. This is consistent with the fact that cellular devices include multiple transmitters and receivers (cellular in multiple bands, Bluetooth, Wi-Fi, etc.) collocated with the GPS receiver, which necessitates a design tolerant of other signals.

- The remaining manufacturer, Topcon, offers devices that show an impact from Ligado's proposed operations only in the 1526-1536 MHz band. Three devices are in this category. However, RAA's analysis did not consider the effect of any additional power limits to which Ligado may be subject in connection with its request that the FCC condition Ligado's licenses on power limitation requirements for that band necessary to achieve compatibility with current and future MOPS that are incorporated into an active TSO from the FAA. The reduced operational power limitation restrictions necessary to satisfy the FAA requirements will resolve any issues with these devices operating in the 1526-1536 MHz band.[36] Topcon has stated that it supports Ligado's applications.[37]

- **Non-Certified Aviation Device:** This device maintained its baseline GPS position accuracy in the presence of Ligado's proposed operations.[38]

RAA conducted further testing to determine the amount of time it takes for various devices to reacquire GPS signals in the presence of Ligado's proposed network. RAA concluded that the reacquisition time for 17 of the 18 devices tested was within one second of its reacquisition time in the absence of any proposed Ligado signal. The remaining device did not experience any increase in reacquisition time when the device's stock antenna was replaced with a filtered antenna.[39]

In sum, the RAA data shows that Ligado's proposal, which was developed in consultation with and reflects the parameters agreed upon by the leading GPS device manufacturers, is compatible with devices in the largest GPS market segments. These proposed operating parameters will enable Ligado to operate a network in a manner compatible with existing GPS operations as implemented by leading device makers. The results also show that even in segments with more demanding requirements such as high-precision devices, GPS companies already are able to produce devices that coexist with Ligado's proposed operations. These results confirm the dependability and resilience of GPS devices.

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[35] *See* NovAtel-Ligado Letter, *supra* note 35.

[36] *See infra* Appendix B.

[37] *See* Topcon-Ligado Letter, *supra* note 37.

[38] Under FAA regulations, unlike certified aviation receivers, these devices may not be used as a primary means of navigation or as a source of precision position information for compliance with various FAA regulations.

[39] *See* Roberson and Associates, LLC, "Summary of GPS Reacquisition Testing by Roberson and Associates," IB Docket No. 11-109, at 2 (Dec. 22, 2016), *available at* https://ecfsapi.fcc.gov/file/122228424456/Ligado%20Ex%20Parte%20Letter%20re%20Reacquisition%20Testing%20(12.22.16).pdf.

NASCTN Testing. Like RAA, NASCTN's testing assessed the actual performance of devices when exposed to wireless signals in the proposed Ligado bands at various power levels.[40] NASCTN's testing was even deeper and more rigorous than RAA's testing with respect to the devices NASCTN selected: each device was tested in isolation for hours, including for as long as 30 minutes at a particular power level in a particular frequency band, in order to obtain statistically significant data. This systematic collection of statistically significant quantities of data allowed NASCTN to determine confidence intervals with respect to its results, rather than merely reporting approximate point-estimates.

NASCTN's results and statistical analyses are consistent with RAA's findings. NASCTN's data, like RAA's, shows that Ligado's proposed operations would have no impact on the location accuracy of GLN devices. With respect to high-precision devices, NASCTN's results indicate that some high-precision devices would be unaffected by Ligado's proposed network, and that retrofitting other high-precision devices with a filtered antenna would ensure that they would be unaffected. NASCTN also tested precision timing devices, and its results show that Ligado's proposed network would not have any effect on devices' timing accuracy.

Volpe Center Testing. It has been more than 1,000 days since DOT held its first workshop on conducting tests of GPS compatibility with non-space commercial use of GPS-adjacent bands. At its most recent workshop, the Volpe Center made clear that its testing did not attempt to collect data regarding the position or timing accuracy, reacquisition time, or any other measure of actual device performance. Rather, the Volpe Center focused on collecting data that can be easily obtained (a 1 dB decrease in a GPS device's self-reported Carrier-to-Noise-Density ratio). This supposed proxy allows for quicker testing but with results that do not measure key performance indicators such as actual location or timing. Volpe used the C/N_0 methodology to collect data from a large quantity of devices and to test 18 different mid-band spectrum frequency bands.[41]

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[40] *See* Dr. William Young et al., NASCTN, *LTE Impacts on GPS: Test and Metrology Plan* (July 22, 2016), *available at* https://www.nist.gov/sites/default/files/revised-test-plan-impact-of-lte-on-gps-22-july-2016.pdf.

[41] Trade-offs that the Volpe Center implemented in order to achieve the speed and breadth of its testing include the following: (1) The Volpe Center tested dozens of devices in the same test chamber at the same time, despite the fact that NASCTN concluded that the presence of multiple devices affects the results and cannot be corrected for with precision. (2) The Volpe Center determined the "baseline" C/N_0 for each device based on only fifteen minutes of testing or less, and determined the impact at each power level for only approximately *fifteen seconds*. By contrast, NASCTN concluded that in order to obtain a statistically significant baseline, each device needed to be studied for several hours; and the impact at a particular power level needed to be observed for as long as 30 minutes. (3) The Volpe Center reported C/N_0 *as measured by the devices*, despite the fact that there is no standard definition for measuring C/N_0 in a methodical and repeatable manner. Indeed, many devices round up or down to the nearest 1 dB. *See* Dr. William Young et al., NASCTN, *LTE Impacts on GPS: Final Test Report* (Feb. 15, 2017), at 3–4, *available at* http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1952.pdf.

The results of the Volpe testing, only a portion of which were presented to the public at a DOT Workshop on March 30, 2017, offered broad, rough survey information but is of limited utility to a regulatory agency needing to make a decision based on the record because unlike both the NASCTN testing and the RAA testing, the Volpe Center has not provided (and will not provide, despite repeated requests by Ligado) access to its data. The extremely limited data that Volpe Center has shared publicly is so narrow as to be useless; a reasoned decision maker can have no confidence that the data is reliable with respect to Ligado's proposal.

Unlike RAA's and NASCTN's test programs, each of which assesses the actual performance of devices, the Volpe Center has tested only the devices' reported Carrier-to-Noise-Density ratio with the goal of recommending an "interference protection criteria." While a device's C/N_0 is not necessarily irrelevant to the device's performance—if the C/N_0 falls significantly in the face of interference, the device at some point will lose lock and fail to function—above that lock-loss threshold, the C/N_0 metric simply does not reveal anything about actual device performance.[42] The test data collected by both RAA and NASCTN shows that for most devices, C/N_0 can *fluctuate by upwards of 5 dB without any impact* of the device's timing or position accuracy. Moreover, RAA and NASCTN found that C/N_0 fluctuates by 3 dB in a "natural state"—*i.e.*, even in the absence of *any* wireless signals in the proposed Ligado bands.[43]

It may be true, as Volpe representatives and others insisted at the March 2017 workshop, that 1 dB data may be easier to access. However, the two tests described above demonstrate that other metrics that examine *actual device performance* not only can be measured but they have been measured across many devices and use cases, in less time than it took to complete the Volpe testing. As a consequence of looking to an imprecise surrogate for actual performance, the Volpe Center data is not reliable and ultimately does not shed light on the question of GPS device performance in the presence of Ligado's proposed network.

To specifically examine whether there is a relationship between C/N_0 and device performance, RAA tested several devices' position accuracy while simply decreasing the GPS signal power by 1 dB at a time (without any signal in any of the proposed Ligado

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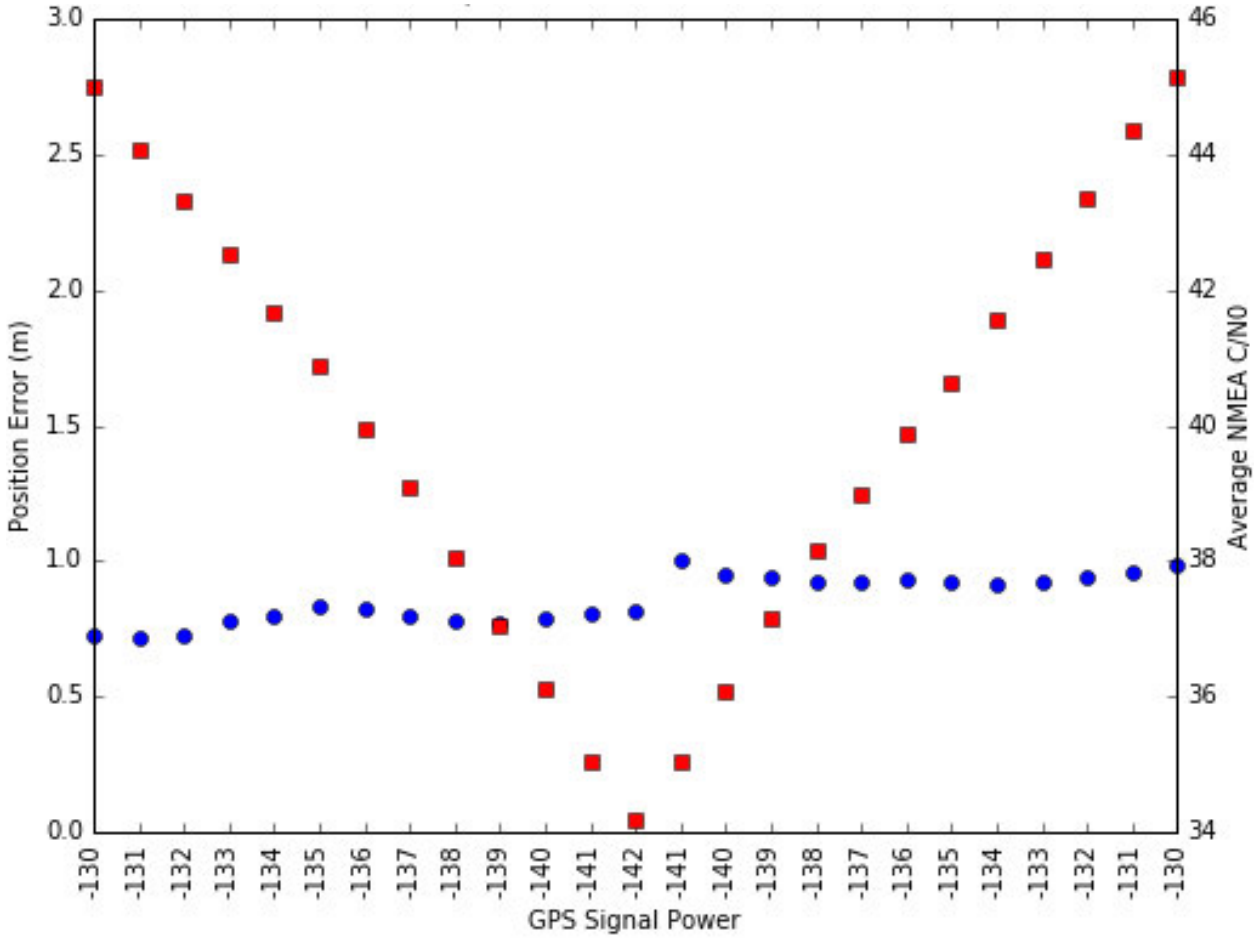
[42] Importantly, this point was acknowledged by the lead Volpe testing official at the March 30, 2017 DOT Workshop. In response to a question about the difference between a GPS device experiencing harm and a GPS device experiencing a 1 dB change in C/No, Mr. Hadi Wassaf said quite plainly: "Again, we mentioned multiple times that when we were looking at 1 dB as a protection criteria, not necessarily as the harm criteria. There are stressful situations, like Chris mentioned, when you drop by 1 dB, you lose lock or other—depending on the stopping CNR value in that environment. But, again, it's—we are saying that is what we are considering tolerable interference level, not harm necessarily."

[43] Theoretical analysis of the relationship between C/N_0 and device functionality is consistent with these empirical data showing that a decrease of 1 dB in C/N_0 does not translate to impairment to GPS device performance. *See* Mark A. Sturza, *Changes in C/N_0 Are Not a Reliable Indicator of KPI Impact* (June 6, 2016), *available at* http://licensing.fcc.gov/myibfs/download.do?attachment_key=1138181.

Figure 4. C/N_0 and Position Error for Trimble SPS985



bands), thus testing the direct effect of changes in C/N_0 on the actual performance of each device.[44] The results show that C/N_0 can vary substantially without any effect on position accuracy. *Figure 4* illustrates RAA's test results for one device, Trimble's SPS985: the red squares show that C/N_0 incrementally decreased by approximately 1 dB from 45 dB to 34 dB, and then incrementally increased back up to 45 dB, while the blue circles show that the device's position error remained consistently in the range of 70-110 centimeters without any relationship to the changing C/N_0.

The publicly available data from the Volpe Center's study are even less useful than a comprehensive set of C/N_0 data would be, because the Volpe Center has reported

[44] Specifically, RAA tested each device by waiting until it achieved GPS lock; running the device with the GPS signal at a power level of -130 dBm for 15 minutes; then incrementally stepping the GPS signal down to -142 dBm, 1 dB at a time, holding each power level for six minutes and capturing the average position error and average C/N_0 during that six-minute window; then incrementally stepping the GPS signal back up from -142 dBm to -130 dBm, again holding each power level for six minutes and capturing average position error and C/N_0.

only one data point for each device in each frequency band: the power level in that band that is associated with a decrease in C/N_0 of 1 dB. As demonstrated by the empirical data discussed above, *this "1 dB" metric bears no reasonable relationship to the actual performance of GPS devices*, and therefore does not contribute any useful information with respect to Ligado's applications. Unfortunately, the Volpe Center has not disclosed (and confirmed at the March 2017 DOT Workshop that it will not disclose) other data it has collected because it has taken the position that the "1 dB" metric should, as a matter of regulatory policy, be used to define an interference protection criteria that would govern the use of all mid-band spectrum, and therefore has taken the position that no other data should be considered relevant.[45]

It should be noted that even the Volpe Center's data, using a flawed metric, nonetheless shows that in *every category* of GPS device manufacturers have produced devices that would not experience even a 1 dB decrease in C/N_0 under Ligado's proposal.

In sum, all of the relevant data demonstrates that Ligado's proposal would not harm GPS devices. Extensive testing by RAA and NASCTN shows that GPS devices' position accuracy and timing accuracy can co-exist with Ligado's proposed network, which would enable America to unlock the economic and technological benefits of putting Ligado's mid-band spectrum to a more productive use.

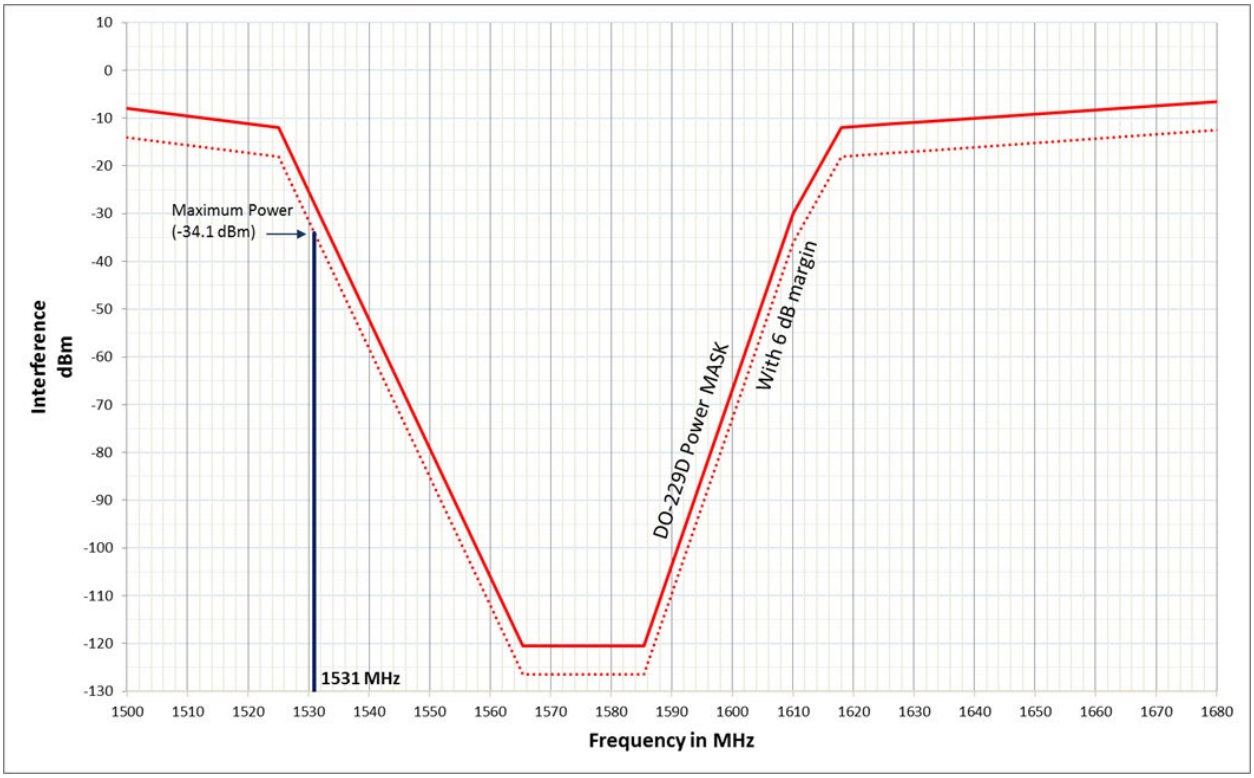
[45] The interference tolerance mask that the Volpe Center has proposed for adoption compounds these problems by taking the position, again as a matter of regulatory policy, that mid-band spectrum power limits must be determined to protect the *worst-performing composite* of the worst-performing devices according to the "1 dB" metric—without regard for the age of the device, the number of such devices actually sold or in use, or how the devices are configured and used in the real world. The result is a bounding mask that would mandate such stringent power limitations that the entire range of spectrum tested by the Volpe Center likely would be wasted because it likely could not be used for any meaningful commercial purpose. The Volpe Center also acknowledged at the March 2017 Workshop in response to a question that *a single poorly designed and poor performing device*, however, old, could set the lowest bound in more than one device category.

APPENDIX B
Ligado's Proposal Will Protect Certified Aviation GPS Devices

Certified aviation GPS receivers are approved by the FAA for primary navigation, flight in instrument conditions, and other regulatory uses, such as position information provided to air traffic control. In its license modification applications, Ligado requested a license condition that would require Ligado to reduce the power of its transmitters operating in the 1526-1536 MHz band to whatever power level is necessary to ensure that Ligado's operations do not exceed the power level mask of any MOPS that is incorporated into an active FAA TSO for a certified aviation GPS receiver, including legacy receivers authorized to continue operating under prior FAA TSOs.

Figure 5 graphically depicts the power level mask provided by a current MOPS incorporated into FAA TSOs for certified aviation GPS receivers (solid red line), along with the 6 dB safety margin that accompanies the mask (dashed red line).

Figure 5. Power Mask

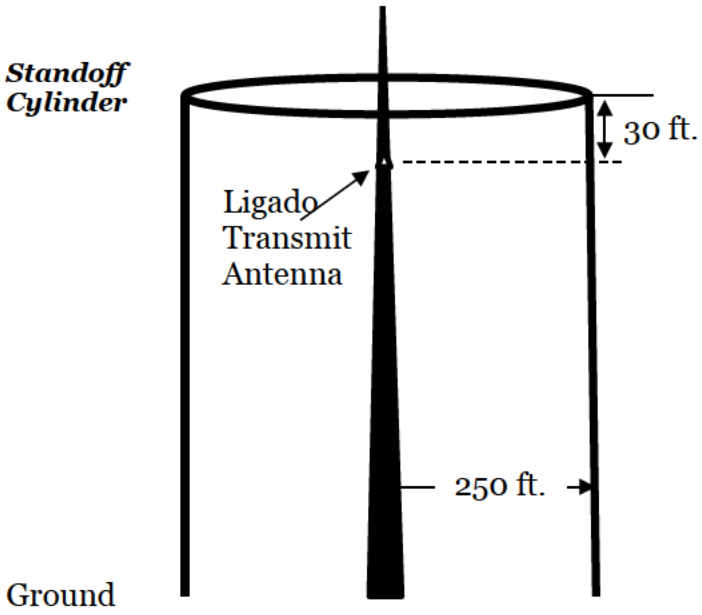


Ligado's operation and maximum power level is depicted (navy blue line) and the power level is shown operating below the mask.

After extensive consultations with the FAA and one of the largest operators of helicopter emergency medical services, Ligado proposed that the airspace protection extend to all navigable airspace of the United States except a cylinder of airspace

immediately adjacent to a Ligado antenna, extending 250 feet laterally from the antenna, and from the ground to 30 feet above the antenna. The selection of these distances was based on a number of factors, including the following:

Figure 6. Standoff Cylinder



1. FAA regulations require that operations closer than 500 feet from a person or object should be conducted with extreme care. Helicopter operators indicated that it would be hazardous to operate closer than 500 feet from an object while relying solely on a certified aviation GPS device to provide navigation guidance to avoid that object. Instead, safe operations in such a situation require flight by visual reference, and the potential degradation of a GPS signal within 250 feet of a tower therefore does not present safety of flight issues.

2. Regulations specific to helicopter air ambulance operations, which are the most likely to operate close to obstructions and away from established airports and heliports, require a pilot to ensure that obstacles along the planned route of flight are cleared vertically by 300 feet (day operations) or 500 feet (night operations).

3. When operating in close proximity to any emitter of radio interference, it is possible that an aircraft's GPS signal reception could be subject to degradation. As a result, helicopter operators indicated that they generally rely on visual cues–not GPS location data–when operating safely in close proximity to a tower.

4. Ligado's proposed protection zone begins 30 feet above the antenna, and helicopter operators indicated that safe operations should generally be further than 30 feet above an obstruction.

Figure 6 depicts a "standoff cylinder" immediately adjacent to a Ligado antenna. Under Ligado's proposal all airspace throughout the United States that is at or beyond the small cylinder immediately adjacent to a tower would be protected for certified

aviation GPS receivers by ensuring that the received signal from Ligado's transmit power did not exceed the MOPS incorporated into active TSOs, as described above.

In conversations with the FAA and FCC, Ligado had identified the following key attributes that it recommends be incorporated into its FCC license condition to implement these requirements:[46]

- Ligado's operation in each base station antenna sector would be limited to a transmit EIRP that is no greater than the power determined by (1) the site limit, minus (2) the aggregate reduction and (3) the probabilistic reduction.

- The site limit and reductions would be calculated as follows:

    - The **site limit** is the transmit EIRP that provides for a peak radio frequency interference that is less than the received power mask specified in any MOPS (including any applicable safety margin) that is incorporated into an active TSO issued by FAA. The site limit is calculated only with respect to the operation of an individual base station antenna sector.

    - The **aggregate reduction** in the transmit EIRP would be 0.9 dB. This reduction reflects the maximum transmit EIRP reduction that is necessary to provide an aggregate received peak radio frequency interference power that is less than the received power mask specified in any MOPS (including any applicable safety margin) that is incorporated into an active TSO issued by FAA.

    - The **probabilistic reduction** in the transmit EIRP would be 1.2 dB. This reduction reflects the transmit EIRP reduction necessary to ensure that a 10^{-6} probability of instantaneous received power is less than the received power mask specified in any MOPS (including any applicable safety margin) that is incorporated into an active TSO issued by the FAA.

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[46] In addition to these conditions, which are designed to address the needs of certified aviation GPS receivers, there are additional limitations, including limitations on out-of-band emissions and maximum transmit power, contained in Ligado's license modification application, filed with the FCC in December 2015. As used in this appendix, certain key terms are defined as follows: *Active Technical Standard Orders* are those that concern minimum performance standards for GPS and are necessary to meet a regulatory requirement for navigation or position information. *Base station antenna sector* is an antenna or array of antennas operating jointly to provide coverage and capacity in a defined geographic area. *EIRP* is the equivalent isotropically radiated power. *Peak radio frequency interference* is determined by the FAA/RTCA models. It is the maximum, deterministic, interference power, calculated over the domain of receiver heights and receiver bank angles, computed by the methodology contained in the October 19, 2016, request from the Federal Aviation Administration to RTCA, Inc.

- To ensure transparency and permit the FAA and the Commission to audit Ligado's compliance with the power calculations, Ligado would be required to submit to the Commission and the Federal Aviation Administration, at least 30 days before commencing transmission at a location, the following:

    - The location of the proposed base station antenna sector (latitude and longitude). Location data is submitted confidentially because of competitive sensitivity. Access to the location data is governed by the FCC's standard rules regarding confidential data (*e.g.*, access is available pursuant to a confidentiality order).

    - The base station antenna sector's radiation center height above ground level.

    - The base station antenna sector's tilt for both mechanical and electrical tilt.

    - The base station antenna sector's specifications, including polarization and pattern.

    - The distance between the proposed base station antenna sector and the nearest adjacent sector operated by Ligado in the 1526 to 1536 MHz band.

    - The transmit EIRP limit for the proposed base station antenna sector (*i.e.*, the site limit, minus the aggregate reduction and the probabilistic reduction).

- For the first two years, Ligado would be required to submit an independent audit of the calculation of the transmit EIRP limit for each proposed base station antenna sector. A nationally recognized auditing and accounting firm would be engaged at Ligado's expense to conduct the audit. The audit will be submitted to the Commission at the same time as the information above; the Commission will put it on public notice.

- Ligado would be required to maintain network operations center procedures for continuous monitoring of the transmit power setting for each base station antenna. Ligado will have a toll-free telephone number for the public to report apparent incidences of interference to GPS that are believed to be the result of Ligado's operations. When Ligado receives credible information indicating that a base station antenna is causing interference by transmitting at a power level in excess of the transmit EIRP limit, Ligado must deactivate the antenna within an hour, and it must investigate and rectify any inconsistent operations before returning to operations. Ligado must notify the Commission of these events. These requirements are in addition to any existing FCC enforcement authority.

- To ensure that its standoff cylinder is not in regulated airspace, Ligado would be prohibited from operating at a location less than 250 feet laterally or less than 30

feet below an obstacle clearance surface established by the Federal Aviation Administration (under 14 C.F.R. Part 77 and implementing orders and decisions).

Figure 7. Obstacle Clearance

APPENDIX C
NOAA's Limited Use of the 1675-1680 MHz Band

Reallocating the 1675-1680 MHz band to be shared with commercial services will not harm NOAA's operations. NOAA's use of this band consists of two key components: NOAA's radiosonde (weather balloon instrument) operations and NOAA's operations involving GOES and GOES-R that occupy a portion of this and adjacent bands. Both components can remain fully protected if the band is shared with a commercial wireless network.

Radiosondes. In May 2014, the National Telecommunications and Information Administration (NTIA) informed the Commission that NOAA radiosondes would be relocated out of the 1675-1683 MHz band to accommodate the results of the AWS-3 auction.[47] Consistent with this plan, NOAA began transitioning radiosonde operations out of the band in 2016 and anticipates completing the transition by 2021.[48] Accordingly, NOAA's radiosonde operations—once a key feature of NOAA's use of the 1675-1680 MHz band—will not be affected by shared commercial use of the 1675-1680 MHz band.

GOES and GOES-R. NOAA's activities relating to GOES and GOES-R have been the subject of much confusion and misinformation. At bottom, all of NOAA's activity related to GOES and GOES-R can continue to function effectively if the 1675-1680 MHz band is allocated to shared commercial use—either because the activity will be wholly unaffected, fully protected, or effectively replaced.

NOAA engages in two activities in managing weather data: data acquisition and data distribution. Each of these two activities relies on both an uplink and a downlink spectrum band. For data *acquisition*, NOAA *uplinks* data collection system (DCS) data from hydrology, seismic, and environmental sensors to NOAA's GOES satellites. This function occurs at 401 MHz.[49] Accordingly, this function will be completely unaffected by shared use of the 1675-1680 MHz band.

NOAA then *downlinks* this data to authorized NOAA and U.S. government receive stations and to organizations that receive a direct readout of this data. For GOES-R, NOAA has begun using spectrum at 1679.7 MHz for this function.[50] Ligado

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[47] *See* Letter from Lawrence E. Strickling, Administrator, National Telecommunications and Information Administration, to Tom Wheeler, Chairman, Federal Communications Commission (May 13, 2014), at Attachment B1, *available at* https://www.ntia.doc.gov/files/ntia/publications/notification_to_fcc_re_est_costs_for_1695_and_1755_bands_05132014.pdf.

[48] *See Comment Sought to Update the Record on Ligado's Request that the Commission Initiate a Rulemaking to Allocate the 1675-1680 MHz Band for Terrestrial Mobile Use Shared with Federal Use*, Public Notice, 31 FCC Rcd. 3813, 3819-20 (2016) ("NOAA Public Notice").

[49] *Id.*

[50] *Id.*

has submitted an uncontested engineering analysis in the record demonstrating that geographic protection zones around NOAA's earth stations can ensure this function continues unaffected.[51]

NOAA also *downlinks* GOES satellite sensor data to NOAA stations. For this function, NOAA uses a downlink at 1673.4-1678.6 MHz for the current generation of GOES satellites and a downlink at 8220 MHz for GOES-R.[52] Clearly, operations at 8220 MHz would not be affected by sharing the 1675-1680 MHz band. With regard to the downlink at 1673.4-1678.6 MHz, two points are in order: first, this band overlaps with the 1670-1675 MHz band that Ligado currently leases and uses. Second, the designated protection zones will ensure NOAA's operations will not be affected by shared commercial use in the band. In fact, the protection zones proposed for the 1675-1680 MHz band are several times larger than the existing protection zones for the 1670-1675 MHz band.[53]

For its data *distribution* activity, NOAA processes GOES-R Broadcast (GRB) data and *uplinks* it for distribution to other NOAA offices. For this function, NOAA uses spectrum at 7216 MHz.[54] Accordingly, this function is not affected by a proposal to share 1675-1680 MHz.

NOAA then *downlinks* GRB data to NOAA stations, using spectrum at 1686.6 MHz.[55] The engineering record establishes that with the proposed protection zones, there will be no impact to this operation. As discussed below, non-NOAA users also would retain full access to the GRB data through the content delivery network the commercial licensee would be required to establish.

NOAA also distributes weather data products to non-NOAA users using a variety of other mechanisms, such as NOAA's DOMSAT downlink at 12 GHz, none of which would be affected by sharing the 1675-1680 MHz band.[56] Finally, and perhaps most tellingly, NOAA also provides various data products *terrestrially* using online distribution via NOAAPORT and USGS EDDN. These online delivery mechanisms will clearly not be affected by the shared use of the band. The charts below summarize NOAA's various activities and how they rely on, or do not rely on, the 1675-1680 MHz band. They also identify the limited ways in which shared commercial use would affect non-NOAA users.

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[51] *See* Alion Task 2 Report, *supra* note 8.

[52] NOAA Public Notice, *supra* note 33, at 3813.

[53] *See* Alion Task 2 Report, *supra* note 8.

[54] *Id.*

[55] *Id.*

[56] *Id.*

NOAA's Use of Spectrum		
Data Transmission	**Spectrum frequency**	**What will happen if 1675-1680 MHz is shared?**
DCPR/DCS data is *uplinked* from public and private monitoring stations to GOES-R satellites.	401 MHz	***Nothing.*** Spectrum is not affected.
DCPR/DCS data is *downlinked* from NOAA GOES-R satellites to various NOAA and USGS receive stations.	1679.9 MHz	***Nothing.*** Designated protection zones ensure no impact.
GOES satellite sensor data is *downlinked* to NOAA stations.	1676 MHz (GOES-NOP)	***Nothing.*** Designated protection zones ensure no impact.
	8220 MHz (GOES-R)	***Nothing.*** Spectrum is not affected.

Distribution of Data		
Data Transmission	**Channel**	**What will happen if 1675-1680 MHz is shared?**
DCPR/DCS data is *distributed* to non-NOAA users.	12 GHz (to DOMSAT)	***Nothing.*** Spectrum is not affected.
	NOAAPORT and USGS EDDN online distribution	***Nothing.*** Online distribution is not affected.
	1679.9 MHz	***Could be affected.*** Remedy is CDN or use of NOAAPORT, EDN, or DOMSAT.
GRB data is processed by NOAA and *uplinked* to GOES for distribution to other NOAA offices.	7216 MHz	***Nothing.*** Spectrum is not affected.
GRB data is *downlinked* to NOAA stations.	1686.6 MHz	***Nothing.*** Designated protection zones ensure no impact.
GRB data is *downlinked* to non-NOAA users.	1686.6 MHz	***Could be affected***, but CDN ensures uninterrupted access for non-NOAA users.

APPENDIX D
Iridium's Technical Claims Ignore a Longstanding FCC Order

Figure 8. 2003 ATC Order

2003 ATC Order (FCC 03-15) states that the "Big LEO systems must be capable of tolerating emissions that range from -47 dBW/4KHz to –58 dBW/4kHz". Normalized for MHz, -47 dBW/4KHz translates to -23 dBW/MHz and –58 dBW/4kHz translates to -34 dBW/MHz

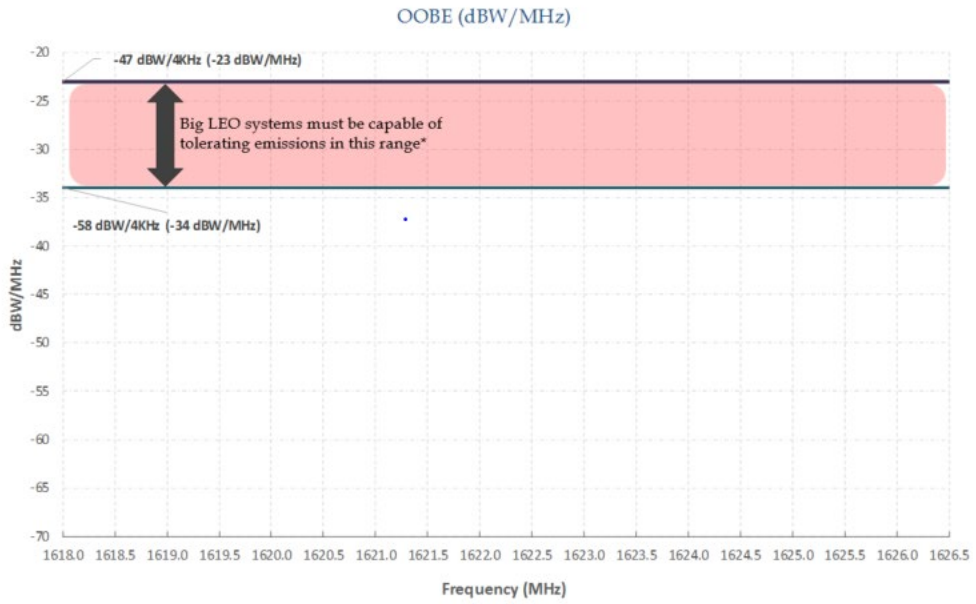

Figure 9. Ligado's ATC Emissions into Iridium's Band

Ligado's proposed OOBE limits are much lower than the tolerable emissions defined in the 2003 ATC order.